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A New Approach to Eliminate the DC Offset in a TDMA Direct Conversion Receiver

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Abstract — **This paper introduces a new method to overcome the problem with the DC offset in a direct conversion receiver which operates discontinuously. Instead of using some kind of DC blocking such as AC coupling, the basic concept is to differentiate, digitize and re-integrate the signal. Differentiation is preferred for time division multiple access (TDMA) systems, since it does not involve a time constant. The proposed method of differentiation is adaptive delta modulation, which provides a digitizing process and a large dynamic range at the same time.**

I. Introduction

The high performance receivers that have been used so far for digital cellular systems have been of the conventional heterodyne type. For applications in future small low cost mobile terminals, these receivers suffer from a high production costs and require a relatively large volume, because of expensive and non-integrable RF and IF filters.

An attractive alternative which solves these difficulties is a receiver based on the direct conversion principle (or zero-IF) as depicted in Fig.1. After optional filtering and amplification, the received signal is power-split and fed to two mixers. The local oscillator frequency is equal to the received center frequency and, consequently, the received signal is converted to baseband in a single step. The output of the mixers spans from DC to $BW_{channel}/2$. This concept was first introduced for SSB receivers [1], but is valid for many different types of modulation and is particularly well suited for digital quadrature modulation schemes.

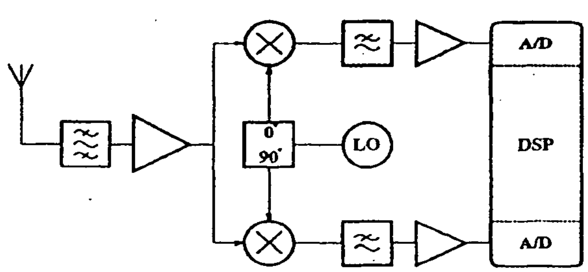

Fig. 1. The direct conversion receiver.

The direct conversion receiver has several advantages over the standard heterodyne. There are no first-order spurious responses (image frequencies), and thus less requirements on RF filtering. All the channel filtering is done at baseband, which makes good selectivity easier to achieve, and active integrated low pass filters can be used. Most of the receiver gain can also be obtained at baseband which minimizes the power consumption. Since there are no IF filters and less requirements on the RF filter, it is possible to reduce the size of the receiver significantly. The direct conversion concept makes it possible to integrate the whole receiver as a single chip, and has been used for pagers [2].

The major drawback with a direct conversion receiver is a DC offset from each mixer in the baseband signals. The DC offset is due to the mixing of carrier leakage from the local oscillator to DC and from offset within the mixer. For a LO-RF isolation of typically 40dB, the DC offset will be much greater than the wanted input signal amplitude, and may saturate baseband amplifiers following the mixers.

There are other problems like the handling of input signals with a large dynamic range (> 80 dB), local oscillator leakage [3], and gain and phase imbalance problems between the I and Q channel [4], which are not considered in this paper.

II. Theory

DC blocking is often proposed as a method of eliminating the DC offset [5, 6, 7], which practically means AC coupling the I and Q signals after the mixer. This works very well for certain modulation types, especially if the received signal is wideband modulated and/or received continuously. But for todays narrow band digital cellular standards with time division multiple access (TDMA), this method suffers from two problems:

- DC blocking distorts the wanted signal because of the high pass filtering.
- DC blocking works only when the DC offset is constant.

In a TDMA system or a frequency hopping system the DC offset will vary and must therefore be established separately for each burst or frequency hop. With a DC blocking system there is a trade-off between the response time and the interference due to the high pass filtering of the received baseband signal. It seems clear that it is essential to find another way of eliminating the DC offset in a TDMA system or frequency hopping system, where the channel bandwidth is narrow.

Another proposed method is DC correction [8], in which the DC offset is removed after digitizing of the signals by subtracting a calculated average. This method works well but requires high performance A/D converters and a large dynamic range in the following digital processing.

The following method [9] is proposed as one way to overcome the DC offset problems:

- Differentiate the I,Q baseband signals to remove the DC component.
- Amplify and digitize the differentiated signal and feed the numerical I,Q values to a DSP.
- Re-integrate the differentiated and digitized signal numerically in a DSP to restore the original signal.
- Use DC correction method to remove the remaining arbitrary constant of integration.

Differentiation is described by the Laplace transform aS simply, while AC coupling is described by $\frac{aS}{1+aS}$. The denominator term $1 + aS$ is a low-frequency pole that causes AC coupling to have a long memory, and this is avoided in the pure differentiator aS.

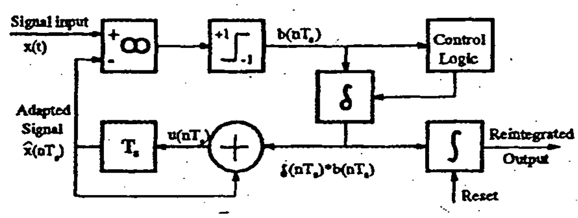

Fig. 2. Adaptive delta modulator.

One method to differentiate and at the same time digitize a signal is to use an adaptive delta modulator [10] as seen in Fig.2, which in its basic form provides a staircase approximation to the baseband signal. The difference between the input signal and the approximation is quantized into two levels, $b(nT_s)$, which corresponds to a negative or positive difference. If the input signal is denoted $x(t)$ and the staircase approximation $u(t)$, the basic principle of delta modulation may be formalized in the following set of discrete-time relations:

$$\begin{aligned} e(nT_s) &= x(nT_s) - \hat{x}(nT_s) = \\ &= x(nT_s) - u((n-1)T_s) \qquad (1) \\ b(nT_s) &= sign[e(nT_s)] \qquad (2) \\ u(nT_s) &= u((n-1)T_s) + b(nT_s) \cdot \delta(nT_s) = \\ &= \sum_{i=1}^{n} b(iT_s) \cdot \delta(nT_s) \qquad (3) \end{aligned}$$

where T_s is the sampling period, $e(nT_s)$ is the prediction error, $b(nT_s)$ is a one bit quantization of the difference, and $\delta(nT_s)$ is the step size.

Due to a large dynamic range in the signal that is to be digitized, the basic linear delta modulator with a constant step size would suffer from a large quantizing error resulting in quantization noise. This quantization noise could be either slope-overload distorsion when the staircase approximation step size is smaller than the slope of the baseband signal, or granular noise in the opposite case when the staircase approximation step size is larger than the amplitude variations in the baseband signal. The performance of the delta modulator is improved significantly when the step size δ assumes a time-varying form, which adapts to the input signal. The adaptation rule used here for the step size $\delta(nT_s)$ can be expressed as:

$$\delta(nT_s) = g(nT_s) \cdot \delta\left((n-1)T_s\right) \qquad (4)$$

where the time varying multiplier $g(nT_s)$ depends on the present binary output $b(nT_s)$ of the delta modulator and the M previous values $b((n-1)T_s), \ldots, b((n-M)T_s)$. The adaptive delta modulator has the nice feature that

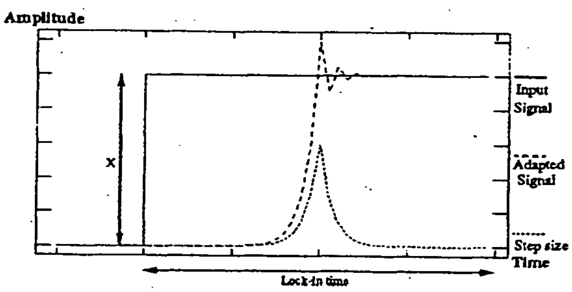

Fig. 3. Maximum adaptation time.

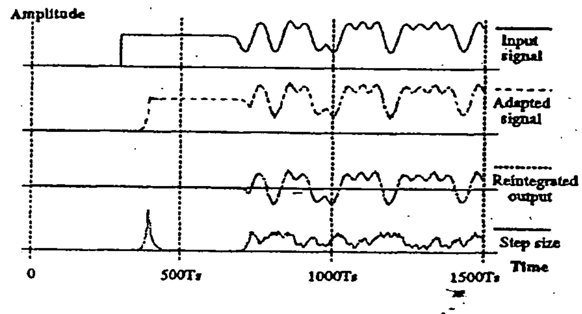

Fig. 4. Simulated start of burst.

within its dynamic range is the signal to noise ratio (SNR) due to granular noise constant and independent of the input amplitude.

The digitizing process proposed is therefore adaptive delta modulation since it is effecting adaptation to the signal level and differentiation to remove the DC offset at the same time. A critical parameter for the adaptive delta modulator is the control algorithm for the step size δ. Different choices of parameters can be evaluated by studying the SNR due to granular noise or by calculating the maximum adaptation time for a step in the received signal (i.e. the DC offset voltage when the receiver is turned on), see Fig.3.

If the DC step is called X and the control algorithm is optimized, the maximum lock-in time $T_{lock-in}$ could be calculated as:

$$T_{lock-in} = 2 \cdot T_s \cdot \frac{\log\left(\frac{X}{\delta_{min}} \cdot (g_{max} - 1) + 1\right)}{\log(g_{max})} \quad (5)$$

where g_{max} is the maximum of the time varying multiplier, and δ_{min} is the minimum step change, which here serves as a start value.

The numerical re-integration starts after the adaptation to the input signal. Ideally the input signal amplitude is zero when the reintegration starts, otherwise an arbitrary constant is introduced. But this arbitrary constant can at least never be larger than the peak value of the received signal. Therefore it does not challenge the dynamic range of the processing as the originally huge offset would have done.

III. Simulations

The proposed adaptive delta modulator solution has been simulated and the results are promising. Fig.4 shows the simulated signals for a large DC offset and a large input signal in a TDMA receiver. First the receiver is turned on, which causes the DC offset in the input signal. After adaptation to the initial step (at $600T_s$) the reintegration starts and here the arbitrary constant of integration becomes zero since the signal amplitude is zero. At $700T_s$ the burst starts and after a short delay the adaptive delta modulator has adapted to the large input signal and the burst is received. In the simulation the adaptive delta modulator uses 24 times oversampling (*6 − steps/symbol*) of the input signal which is GMSK modulated.

Due to the staircase approximation of the input signal, there will be a degradation of the bit-error rate (BER) performance of the receiver compared to an ideal receiver. Fig.5 shows the degradation of the simulated receiver compared to the ideal receiver. The simulation is done with a GMSK modulated input signal and a simple phase shift detection algorithm.

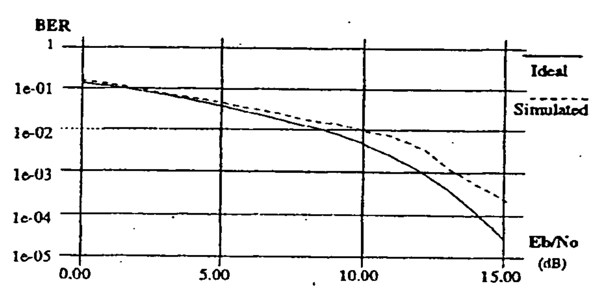

Fig. 5. BER simulation.

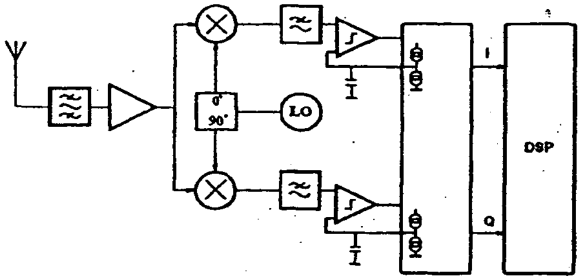

Fig. 6. Implementation.

IV. Implementation

One way to implement the adaptive delta modulator is by using well defined charge pumps for generation of the step size. The differentiation takes place by letting a charge to build up on a capacitor. This voltage is compared with the baseband signal in a comparator and the output signal corresponds to the sign of the difference. The step size variable δ is the amount of current that charges the capacitor. This current is chosen by selecting the proper charge pump or combination of charge pumps.

The re-integration is done simply by accumulating the step size by sign in a accumulator. This accumulator should be reset after the lock-in but before the burst.

V. Conclusions

A new approach to eliminate the DC offset in a direct conversion receiver has been presented. The concept is particularly well suited for use in a TDMA system, where the DC offset varies between each burst. The basic idea to use an adaptive delta modulator to differentiate and digitize the signal has been examined theoretically. Simulations has also been performed which supports the theories. Finally a suggestion of how to implement the adaptive delta modulator is made. It seems as this method provides a solution to the DC offset problem and further investigations and implementation will be done.

References

[1] D. K. Weaver. "A third method of generation and detection of single sideband signals." In *Proc. of IRE*, pages 1703–1705. IRE, December 1956.

[2] I.A.W. Vance. "Fully integrated radio paging receiver." In *IEE Proceedings F, vol 129, 1*, pages 2–6. IEE, February 1982.

[3] H. Tsurumi and T. Maeda. "Design study on a direct conversion receiver front-end for 280 MHz, 900MHz, and 2.6 GHz band radio communications systems." In *Proceedings of the 41st IEEE Vehicular Technology Conference*, pages 457–462, May 1991.

[4] M. Dickinson. "Digital matching of the I and Q signal paths of a direct conversion radio." *Journal of IERE*, 56(2):75–78, February 1986.

[5] G. Schultes, A.L. Scholtz, E. Bonek, and P. Veith. "A new incoherent direct conversion receiver." In *Proceedings of the 40th IEEE Vehicular Technology Conference*, pages 668–674, May 1990.

[6] B. B. Lusigan P. Estabrook. "The design of a mobile radio receiver using a direct conversion architecture." In *Proceedings of the 39th IEEE Vehicular Technology Conference*, pages 63–72, May 1989.

[7] K.Takahashi, M.Mimura, M.Hasegawa, M.Makimoto, and K.Yokozaki. "A direct conversion receiver utilizing a novel FSK demodulator" and a low-power-consumption quadrature mixer. In *Proceedings of the 42nd IEEE Vehicular Technology Conference*, pages 910–915, May 1992.

[8] A. Bateman and D. Haines. "Direct conversion transceiver design for compact low-cost portabel mobile radio terminals." In *Proceedings of the 39th IEEE Vehicular Technology Conference*, pages 57–62, May 1989.

[9] P.W. Dent. "DC offset compensation." *U.S. Patent Application No. 07/578,251*, September 1990.

[10] N. S. Jayant. "Digital coding of speech waveforms: PCM, DPCM, and DM quantizers." In *Proceedings of the IEEE*, pages 611–632, May 1974.